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# Comparative Study On Indoor Air Quality Variation While Burning Differnet Firewood Species In Gatlang, Rasuwa, Nepal

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# Abstract

Indoor Air Pollution (IAP) from smoky cooking fires causes deaths over 22,800 per year being the fourth leading cause of death in Nepal. The study aims to compare the pollution level particularly Carbon Monoxide (CO) and Particulate Matter ($PM_{2.5}$) in different firewood species. Two households one with ICS and TCS is selected purposively to monitor the concentration of pollutants in Ward no. 3 of Gatlang, Rasuwa, Nepal. IAP Meter based on Laser Sensor principle is used to monitor real time concentration of $PM_{2.5}$ and CO concentration.

24 hours mean concentration of $PM_{2.5}$ and 8hours mean average concentration of CO are found to be above the WHO and National Indoor Air Quality Guidelines i.e. For ICS using household the concentration is found to be 155.26μg/$m^3$ and 9ppm respectively and household using TCS is found to be 385.12μg/$m^3$ and 12.2ppm). Both concentrations are found less in *Abies Spectabilis* than other species. Positive correlation is found in both households along with moisture content, amount of firewood used, etc. This result suggests the use of *Abies Spectabilis* as it emits less emission as compared to other species as it has less moisture content that reduces the concentration of air pollution.


# Introduction

Exposure to IAP from burning solid fuel such as wood, dung, crop residues for cooking and heating causes the premature deaths of 4 million people each year [1]. Inefficient combustion of biomass fuel and poorly regulated energy production are the major cause of air pollution, is considered as single most man-made effect [2]. Due to inefficient combustion of fuel several health damaging chemicals and pollutants such as particulate matter ($PM_{10}$ and $PM_{2.5}$), carbon monoxide, benzene, and formaldehyde and nitrogen oxides are formed.

Around 42.2% of the population is exposed to household air pollution in most of the middle and low-income countries and it ranks as the eighth greatest risk factor causing morbidity and mortality [3]. In developing countries, IAP is the top-fourth risk factor driving overall morbidity and mortality. Household air pollution causes non-communicable diseases including stroke, ischemic heart disease, chronic obstructive pulmonary disease (COPD) and lung cancer [4]. Apart from that, various respiratory symptoms including dry cough, phlegm production and breathing difficulties along with back pain, cardiovascular disease, cancer, blindness and low birth rates have also been linked to indoor air pollution [5].

Various factors affect the concentration of pollutants which includes: condition of household and biomass burning cook stove. Along with that several other factors such as: type of fuel, time spent in cooking, structural characteristics of houses, and ventilation practices of household (opening of windows, doors, etc.), cooking and heating methods, changes in season also causes changes in pollutant concentration [6]. However, the extent of pollution varies upon the cooking activities within the day and between the days [7].

Similarly, cooking with solid fuels such as wood over an inefficient stove leads to the exposure of incomplete combustion of various particles inside the domestic environment [8]. Factors which affects the affecting combustion of woods are moisture content, ash content, size of log, firebox size, shape and materials, flue gas outlet dimensions, air supply, stack height, natural draft, air supply and mixing, combustion rate, fuel loading and operation habits [9].

Household pollution from smoky cooking fires causes over 22,800 deaths per year [10]. It contributed to 1.6 million of premature deaths/year occurred in developing countries, being the 4th leading cause of death with 8700 deaths occurring in Nepal alone [11].

Burning of biomass fuel in traditional cook stoves (TCS) is one of the major means of cooking in rural areas in most of the developing countries [12]. Typical wood-fired cook stoves and open fires emits various particles such as: carbon monoxide, particulate matters and other noxious fumes which are up to 100 times higher than the recommended limits set by WHO [13]. It has low efficiency and are prevalent in rural areas, hence more fuel is consumed along with higher incomplete combustion of particles [14]. A study carried out in rural areas of South India showed that if an improved cooking stove replaced the traditional mud-built cooking stove, each family could reduce its annual fuel wood consumption by about two-thirds [15]. According to a report ICS saved over 88 kg of fuel wood per month on average. The report quotes the use of ICS has also reduced the cooking time, time of firewood collection, emission of greenhouse gas, lowers the pressure on forest for firewood extraction and reduces the health hazard [16].

Approximately 80 percent of energy consumption in Nepal is from the fuel wood including animal dung and the agricultural residue [17] and mountain areas being isolated, fragile and inaccessible, inhabitants are more dependent on the traditional cooking fuels. As a result, indoor air pollutants have poses great threat to human health (especially women and children who spend more time in kitchen) [18]. Also because of the comparatively cold weather in the mountain region throughout the year (mainly in the winter season), the need for firewood and other alternatives fuels becomes highest during winter season resulting more pollutants due to restricted ventilation.

The aim of the study is to compare the pollution level in ICS and TCS by burning different firewood species. There is lack of research related to variation in pollution regarding to different species especially in Rasuwa where air pollution resulting from biomass burning is common. This research will help to examine the variation in air quality while burning different types of firewood species. In order to know about the impact of burning different firewood species, the concentration of pollutants such as CO and $PM_{2.5}$ should be determined. This research will help to identify the level of pollution while burning different firewood species which will help the people to use the species which creates less pollution and to reduce the health effect to some extent. The district is selected as a study site because of the mixed cooking system (traditional and modern types), the cooking styles and household characteristics which resembles to other parts of the country.

# Materials And Methods

The study is a comparative study between two cook stoves i.e. ICS and TCS using random and purposive sampling, conducted between February 13$^{th}$ to March 9$^{th}$, 2019 at Ward no. 3 of Aamachodinmo Rural Municipality, Rasuwa, and Province No. 3. The study area lies at an elevation of 2313m with longitude and latitude of 28°9’22”N and 85°15’18”E, respectively.

It lies in temperate zone with major vegetation type of *Alnus nepalensis, Tsugadumos, Abies spectabilis, Rhododendron sps, Quercus semicarpifolia* and many other medicinal plant species like *Alvumvisum, Swertiachirata, and Juglanregia* etc.

The population of 1267 with 622 male and 645 females are living in 292 individual households [19]. The majority of people are Tamang while few belong to Biswokarma. The major source of energy for cooking and heating is firewood whereas, the household are of mainly two types; namely typical old household (black house) and new households.

Both quantitative and qualitative data are carried out during the study. Both primary and secondary data are collected, monitored and analyzed.

Field visit is carried for the collection and monitor primary from 13$^{th}$ February till 9$^{th}$ March. Sampling is carried out by cluster sampling method followed by systematic sampling protocol in each cluster and sample size is determined by using [20] at 95% level of confidence with standard error of 0.05. The formula is as below:

$$n = NZ2 * p(1-p)/[Nd2 + Z\hat{}2p(1-p)$$

Where,

n = Sample size

N = Total number of households

Z= value of standard variant (at 5% level of significance, Z= 1.96)

p = Estimated population proportion (10%)

d = Error limit 5%

Altogether 68 household are selected by this method from total of 292 households. Cluster sampling with total of four clusters followed by systematic sampling method is applied for questionnaire survey of total 68 households where 17 households from each cluster are surveyed.

Criteria for selection of the houses is made on the basis of the following criteria adapted from [21]

- Functional homestead (at least mother and children present),

- Cook daily in designated cooking area in home,
- Use firewood as main fuel on a daily basis,
- Firewood is either bought or collected in fixed bundles on a regular basis
- Involvement in the kitchen work

Focus group discussion is carried with women's' group focusing on types of household energy, past and presents condition of the forest, availability of firewood, consumption of firewood, challenges and opportunities regarding energy sources and health issues related to IAP.

Using purposive sampling technique, two households are selected from the traditional houses (black house) on the basis of use of fuel wood as the major cooking source. The households are chosen on the basis type of cooking stove i.e. TCS and ICS based on questionnaire survey where 24hour continuous monitoring of $PM_{2.5}$ and CO is carried out. The households for the sampling is chosen away from roads in order to exclude suspended particles generated through vehicular movements. Daily wood measurements are taken from 13$^{th}$ February to 9$^{th}$ March, 2019. IAQ is assessed by continuous monitoring for 24hour in sampled households by following the sampling protocol by National Indoor Air Quality Standard (NIAQS) and implementation guideline [22]. Households are instructed to only use wood from the weighed pile that day and store the newly collected pile for the next day. The wood is tied in one or more bundles and weighed [23].

# Results

Questionnaire survey is carried out in 67 households regarding fuel wood consumption, using random sampling during the study period from 12$^{th}$ February to 7$^{th}$ March, 2019. The purposive sampling is carried out in two households one with ICS and TCS for 5 consecutive days in each household.

Mostly two forms of energy sources i.e. traditional and alternative sources are observed in the study area. Figure 2 represents the total number of households dependent upon various energy sources. Firewood is used in all the houses for cooking food, for space heating, preparing animal food and for making alcohol. Firewood used as energy source for cooking in winter season is 88% followed by 11% Liquefied petroleum gas (LPG) whereas during summer season the increase in use of LPG is 29.4% whereas the use of firewood is 70.6%.

From the study it is found that 22% of the households has attached kitchen with partition while 49% households has separate kitchen outside the house and 29.40% of households has attached kitchen without partition within the house.

Based on the types of cooking stoves, 87% of households has TCS whereas, 13% of the households had ICS as shown in Figure 5.

More than 9 species of trees are used by the local people for firewood. As per the rules and regulations of the forest office the local people are allowed to collect dried, dead and fallen branches and twigs, people collected them and stored them for winter season. The major tree species that are used as firewood are presented in table below:

Among these species five species mainly *Eurya acuminata, Pinus wallichiana, Abies spactabilis, Alnus Nepalensis and Rhododendron Falconeri* are mostly commonly used.

As the village lies near the forest so, villagers fetch the firewood easily from nearby forest. Out of total respondents 24% response that firewood is easily accessible and economical. Similarly, 11% response that it takes less time to cook, followed by 7% who believes that it enhances the taste, 9% response it is easy excess heating whereas 49% believed in all of the mentioned options which is shown in Fig. 6.

The average firewood consumption of a single household is found to be 7.195kg/HH/day. Per capita firewood consumption of the households using TCS and ICS is found to be 1073.1kg/person/year and 675.25kg/person/year respectively.

### *Indoor Air Pollution*

The average 1hour concentration of CO in the household using TCS and ICS is found below the NIAQS value and WHO value i.e. 35ppm. Figure 7 and 8 represent the concentration of individual households in two different types of stoves.

### *Particulate Matter ($PM_{2.5}$)*

The average 1hour concentration of $PM_{2.5}$ in the household using ICS and TCS using different firewood species is mentioned. Both the households have exceeded the NIAQS value i.e. 100µg/$m^3$ and WHO value i.e. 60µg/$m^3$ as shown in Figure 11 and Figure 12 where the concentration of *Pinus wallichiana* is highest which is followed *by Rhododendron Falconeri, Eurya Acuminata, Alnus Nepalensis* and *Abies Spectabilis.*

The 24 hours $PM_{2.5}$ average in both the houses using ICS and TCS is found to be 155.3µg/$m^3$ and 367.9µg/$m^3$respectively. It exceeds the NIAQS Value i.e. 60µg/$m^3$ as well as the WHO guideline i.e. 25µg/$m^3$. Fig 8 and Fig 9 represent the concentration of $PM_{2.5}$ in two different houses using ICS and TCS followed by five different species.

Correlation between firewood and moisture content in household using ICS (p= 0.005687, = 0.9713) which shows both firewood and moisture content are strongly correlated with each other similarly, the correlation between firewood and moisture content of household using TCS is (p= 0.0007258, r= 0.9928) which also shows the strong correlation between the parameters.

The correlation carried out between the indoor air pollutants and factors contributing to them in the households with ICS and TCS reveal that there is positive correlation between $PM_{2.5}$ and moisture content and CO and moisture content (r = 0.633, r = 0.647), of amount of firewood with moisture content (r = 0.57, r = 0.581) and cooking phase (r = 0.721, r = 0.69).

# Discussion

The study showed firewood as the major energy source for cooking (88%) and heating purpose (12%) which represents the high dependency on fuel wood especially in winter season because of its ease accesses as compared to other sources of cooking fuel. Various factors such as size of the family, livestock holding capacity cause fluctuation in the use of firewood. Apart from those other factors like level of education, distance and the time devoted for collection of firewood ethnicity, settlement location [24].

The use of firewood is similar to the national situation i.e., about 80 percent of energy consumption in Nepal is from the fuel wood including animal dung and the agricultural residue [17]. Such high dependency on firewood might be because of lack of other economical and accessible source for heating purpose as the area lies in Himalayan region which is similar to the study of [25] in Manaslu conservation area where 2135 kg/day firewood used in households using ICS whereas, 349 kg/day firewood used in households using TCS.

### Concentration of pollution with respect to individual species

Among different firewood species used for the study the physio-chemical properties of *Abies Spectabilis* shows the moisture of 45.6%, calorific value of 21.2kJkg$^{-1}$, density of 0.81, ash 1.9% and FVI 903.8 [26] Similarly, the average 8hours concentration of CO is found to be 7 ppm, average 24hours concentration of $PM_{2.5}$ is found to be 120.0 μg/m$^3$ also, the amount of moisture content is found to be 8% whereas, the average amount of firewood consumed is 6 kg for household using ICS.

Similarly, *Eurya Acuminata* has density of 0.53, moisture content 48%, ash 1.49% whereas, the calorific value is found to be 21.02 kJkg$^{-1}$ from the physio-chemical properties, calorific value of 19.6 kJ/g, density 0.84 g/cc, ash 1.7%, biomass ash ratio 56.1%, moisture 46.2%, Nitrogen 0.22% and FVI 2096 [27]. The average 24hours concentration of $PM_{2.5}$ is found to be 201.0 μg/m$^3$ whereas average 8hours concentration of CO is found to be 9 ppm. The amount of moisture content is found to be 10% whereas the average amount of firewood consumed is 8 kg. Though this species has densest wood but also has high ash content and makes it less desirable [28].

The fuel wood characteristics of *Alnus Nepalensis* shows moisture content of 37.41%, calorific value of 15.13kJkg$^{-1}$, density 0.46%, ash content 1.1%, silica 0.60 fixed carbon 27%, biomass and ash ratio 90.90%, Nitrogen 0.423%, Total carbon 66.15%, volatile matter 34.09% and FVI value of 1709 [29]. *Alnus* has energy content of 17.30, moisture content 46%, biomass/ash ratio is 17%, density of 0.32, ash 1.77%, FVI of 673.5 [28]. Similarly, from the study, the average 24hour concentration of $PM_{2.5}$ is found to be 150.1 μg/m$^3$ whereas, the average 8hour concentration of CO is found to be 8 ppm. The moisture content is found to be 9.8% whereas the average firewood consumption is 7 kg. From the study conducted by the amount of silica content in *Alnus Nepalensis* is 0.65 which is lower than the preferred value (0.70%) which shows that the species does not retain the heat for longer period of time after the fire has died off and increases cold during winter time and increase the amount of firewood consumption [29].

*Pinus Wallichiana* has moisture content of 55.09 ± 0.83, calorific value of 19.30 ± 0.34 $KJ/kg^{-1}$ density 0.49 ± 0.01, ash 1.69 ± 0.07%, silica 0.75 ± 0.01%, fixed carbon 24.45 ± 0.35%, nitrogen 0.117 ± 0.001%, total carbon 60.40 ± 0.78% and FVI 560 ± 1.11 [29]. From the study, the concentration of $PM_{2.5}$ is found to be 267.1 $\mu g/m^3$ whereas concentration of CO is found to be 10.9 ppm. The average amount of firewood consumption is found to be 8.41 kg whereas moisture content is found to be 13.2% which is comparatively higher than other species. As comparatively higher level of nitrogen content and volatile matter is present in this species results in formation of different oxides of nitrogen while burning which leads to different health hazard and environmental pollution [30].

According to value *Rhododendron Falconeri* has moisture content of 49%, density 0.62, ash 1.28%. From the study the average 24hours concentration of $PM_{2.5}$ is found to be 231.9 $\mu g/m^3$ and average 8hours concentration of CO is found to be 10.1 ppm. The moisture content is found to be 12.4% whereas average firewood consumption is found to be 10.52 kg.

Higher moisture content of wood the lesser is the energy output as it is the major determinant of its combustion rate and decreases its calorific value. *Abies Spectabilis* creates less pollution in comparison to that of other species because of its low moisture content (45.6%), high calorific value (21.2$KJ/Kg^{-1}$) [30]. As calorific value and density of *Abies Spectabilis* is higher as compare to that of other species which makes it to have more positive characteristics than that of other species. However, due to the presence of high water content and high ash content in *Pinus Wallichiana*, *Alnus Nepalensis*, *Rhododendron Falconeri* makes this species with negative characteristics i.e. higher pollution concentration than that of other species.

As FVI value plays an important role to determine the desirable wood, the FVI value of each species is taken from the studies carried out by different researchers. Study found that the FVI value of *Rhododendron Falconeri* (1922.0) is highest followed by *Eurya Acuminate* (1358.6), *Abies Spectabilis* (903.8), *Alnus Nepalensis* (673.5) and *Pinus Wallichiana* (558.89) however, the pollution level is found higher in *Rhododendron Falconeri* and *Eurya Acuminate* because of its high moisture content [30].

In poor developing countries, incomplete combustion of traditional sources often burned in poorly functioning stoves are proven to emit health hazardous $PM_{2.5}$, benzene, formaldehyde, hydrocarbons and CO have been shown to damage health of humans in household environment [31].

From this study 1hour CO concentration of both houses i.e. ICS and TCS is found below the NIAQS guideline. However 8hours concentration of CO in both cooking stoves is surpassed the standard for safe health that passed the permissible value. It might be because of the longer cooking hours, inefficient performance of ICS. According to a study conducted by Aprovecho Research Center (ARC), which shows that the chimney stoves are less efficient as it is slower to boil and consume more fuel and had Therefore, increases the invisible $PM_{2.5}$, CO and powerful climate forcing pollutants (methane and black carbon) inside rural household.

Similarly, average 1hour and 24hours concentration of $PM_{2.5}$, both houses with ICS and TCS has exceeded NIAQS and WHO guidelines which is similar to the result of previous study [32]. The reason noticed during study period is the number of ventilations, dryness of the firewood, orientation and placement of chimney for ICS, opening or closing of the windows during cooking time, characteristics of the houses, methods of cooking, etc.

From the study it is found that doors and windows are closed to cope with the extreme cold condition. People usually open their doors and windows only for a short period of time, although the firewood is cut and is placed in a dry place but due to harsh weather the wood are moist which might be the cause of increase in concentration of pollutant.

Similarly, PM concentration is highly affected by the various activities such as sweeping, movement of the people, fuel burning duration and time spent in the kitchen during fuel burning. It also varies with the wood added, stirred, removed, pot placing while stirring food.

Cooking habits and cooking methods give rise to high emissions and high peaks of CO and $PM_{2.5}$ that occur during cooking [36] and diffuse rapidly into living spaces [33]. From the study it is found that the cooking hours (8hours for ICS and 10hours for TCS) also influence to increase the concentration of pollutants which is higher than the study conducted in three districts of Nepal in Illam i.e. 6-7hours, 4hours in Dang and 5hours in Dolakha. The reason for this might be due to geographical and cultural differences, in addition the differences in stove use and maintenance [34].

Although CO has been applied as surrogate measure by various researchers the findings suggests limited utility as proxy in this setting. Variation in correlation can be explained by cooking characteristics, fuel type and cooking behavior [35]. The 1hour correlation between CO and $PM_{2.5}$ is found to be strongly correlated ($r = 0.9015$) which is similar to that of the study of Muralidharan et al., 2015 [36] where p-value is 0.82 for household using TCS and other alternative cooking stove. Various researches also lead to conclusion that household characteristics along with condition of stove primarily influence emission and pollutant dilution which can determine $PM_{2.5}$ and CO relation as studied by Naeher et al., 2001 [37].

# Conclusion

This study found that firewood is the major source of energy for the people as it is easily accessible. Firewood burning inside enclosure contributes in the concentration of PM2.5 and CO. The concentration of both types of pollutants exceed the safe limit recommended by WHO and NIAQS Guidelines for the safe health.

Emission from ICS is comparatively lower in terms of CO and $PM_{2.5}$ (9 ppm and 155.26 $\mu g/m^3$). As compared to emissions from households with TCS (12 ppm, 385.12 $\mu g/m^3$). CO concentration is in safe limit recommended by NIAQS Guideline in ICS while $PM_{2.5}$ exceeds the permissible standard in both households with ICS and TCS. It is found that burning of *Abies spectabilis* has low concentration of $PM_{2.5}$ and CO as comparison to that of other species that helps in the reduction of pollutant as it has low moisture content and high calorific value.

$PM_{2.5}$ and CO concentrations are positively correlated (r = 0.90) with the amount of firewood used (r = 0.571, r = 0.59), moisture content (r = 0.633, r = 0.647) and with cooking phase (r = 0.71, r = 0.69).

Similarly, the health impact is found more in women as compared to other family members. problems such as wheezing and eye irritation (46%), coughing (16%), chest pain (26%), difficulty in breathing (7%) and others (4%) because of their regular exposure. Hence, though the use of ICS reduce pollutant to some extent is an effective way for the community because of its various advantages associated with it apart from that use of *Abies Spactabilis* species would help in the reduction of pollutants.

# Ethics Declarations

### Competing interests

The authors declare that they have no competing interests

### Availability of data and materials

No such sources of data or materials are used for this study except own field monitoring data and agencies standard guideline values.

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### Contributions

All the authors have contributed to the structure, content, and writing of the paper. All authors read and approved the final manuscript.

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# Tables

Table 1
Plant Species used as firewood

| ***Local Name*** | ***Scientific Name*** |
|---|---|
| Pibi | *Eurya Acuminata* |
| Thangsing | *Alnus Nepalensis* |
| Chesing | *Pinus Wallichiana* |
| Jhangsing | *Abies Spectabilis* |
| Tamar | *Rhododendron Falconeri* |

Table 2
Per Capita Firewood Consumption of Household using TCS

| **Average firewood consumption (kg/HH/day)** | **Total number of family** | **Family members** | **Per capita firewood consumption (kg/person/day)** | **Per capita firewood consumption (kg/person/year)** |
|---|---|---|---|---|
| 11.168 | 1 | 3 | 2.94 | 1073.1 |

Table 3
Per Capita Firewood Consumption of Household using ICS

| **Average firewood consumption (kg/HH/day)** | **Total number of family** | **Family members** | **Per capita firewood consumption (kg/person/day)** | **Per capita firewood consumption (kg/person/year)** |
|---|---|---|---|---|
| 7.446 | 1 | 3 | 1.85 | 675.25 |

Table 4
Correlation of $PM_{2.5}$ and CO with factors contributing to IAP in household using ICS and TCS

| Parameters | PM | CO |
|---|---|---|
| Moisture Content | 0.633** | 0.647** |
| Firewood consumption | 0.571* | 0.591* |
| Cooking phase | 0.721** | 0.69** |
| * Significant at 0.05 level (2 - tailed) | | |
| ** Significant at 0.01 level (2- tailed) | | |

# Figures

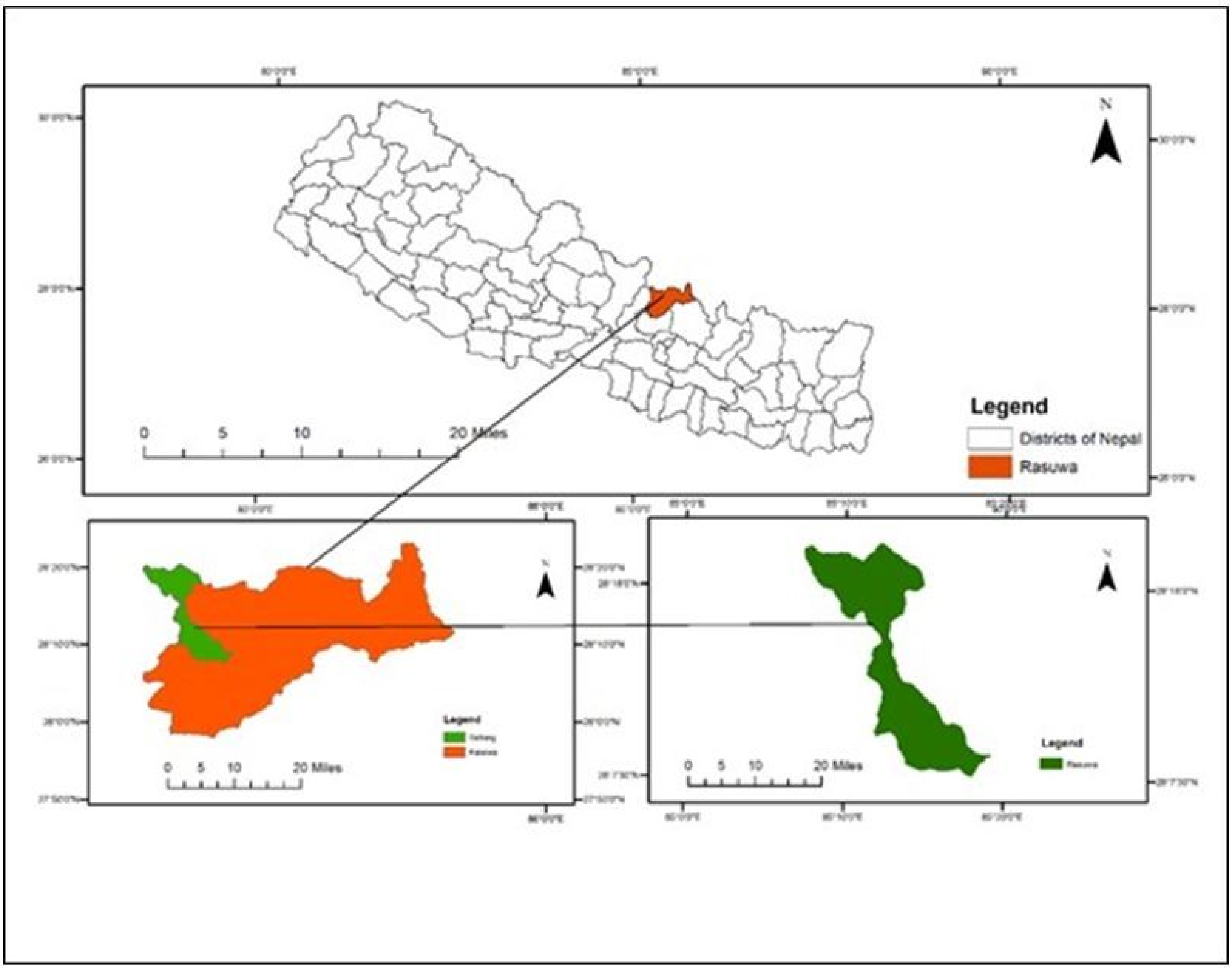


**Figure 1**

Map of Gatlang, Rasuwa Nepal

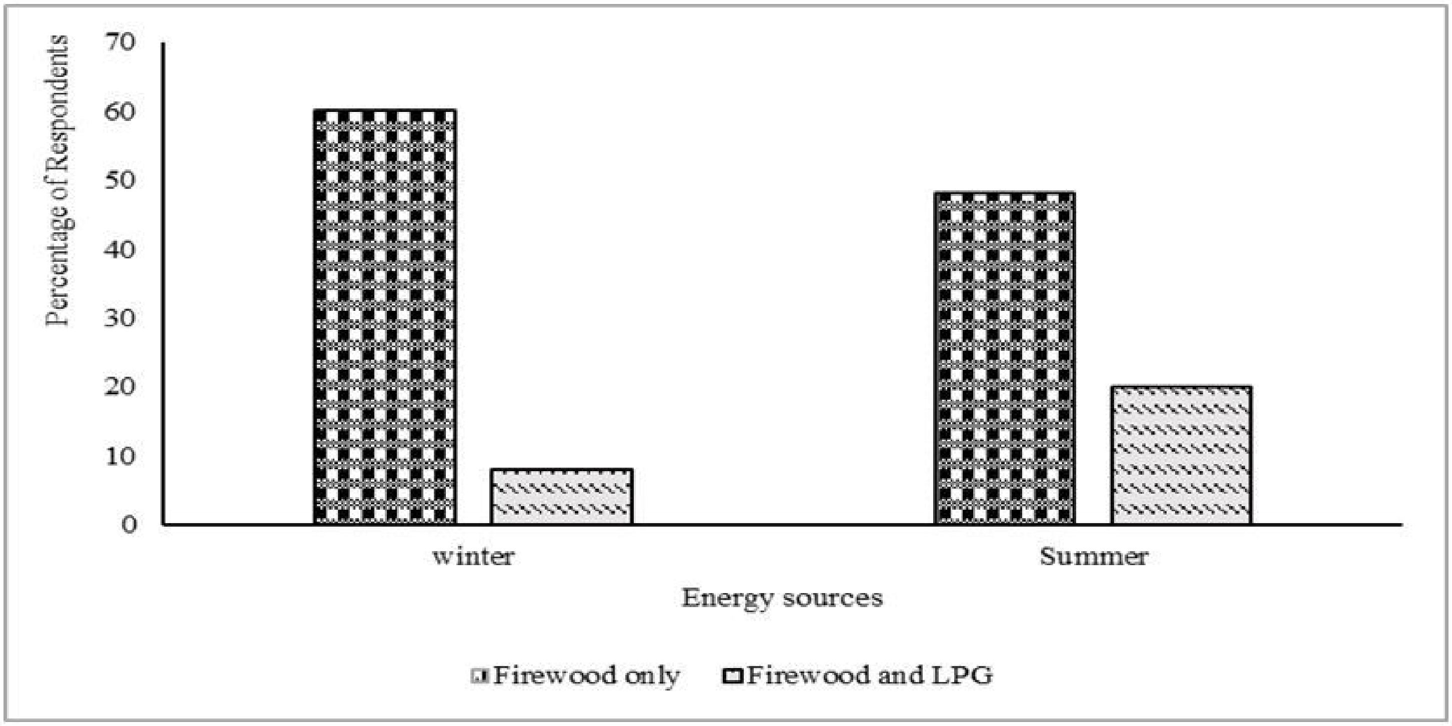



**Figure 2**

Energy source for cooking

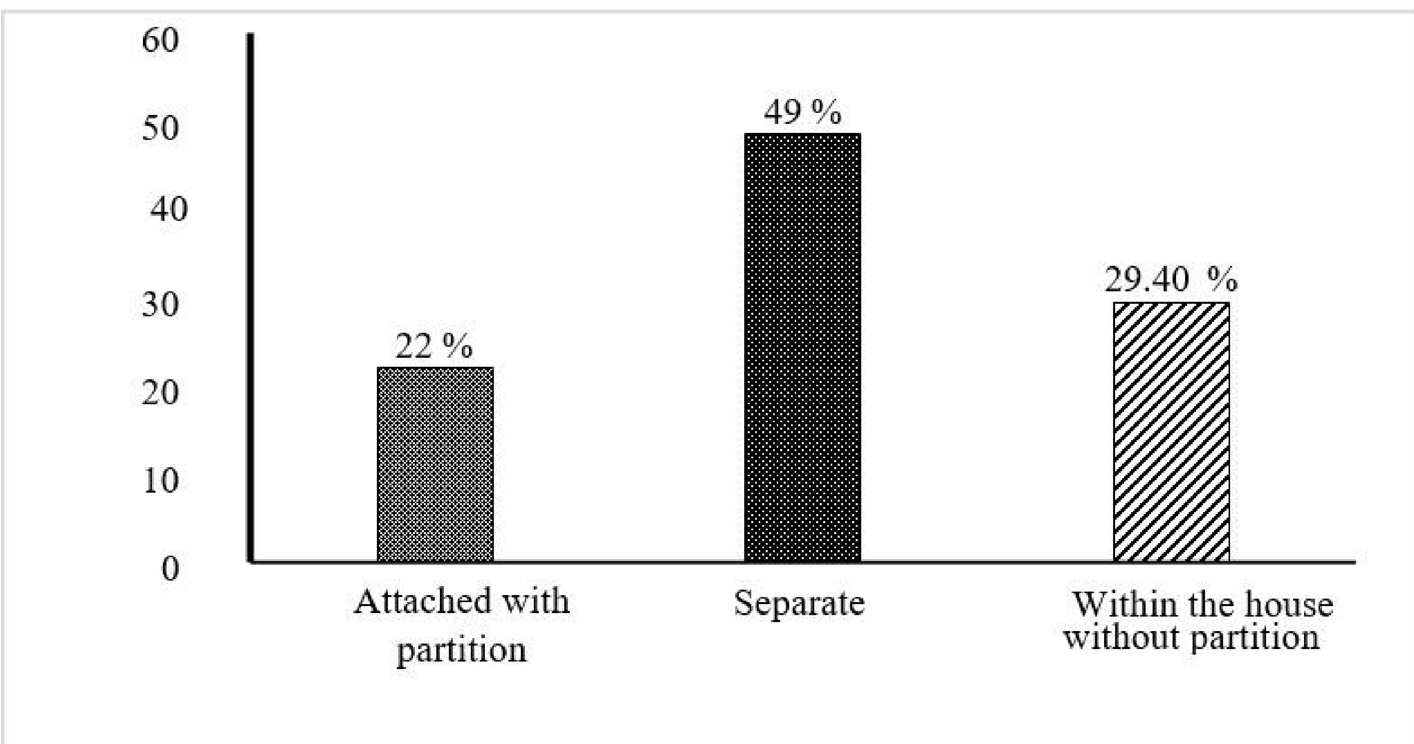



**Figure 3**

Kitchen Configuration

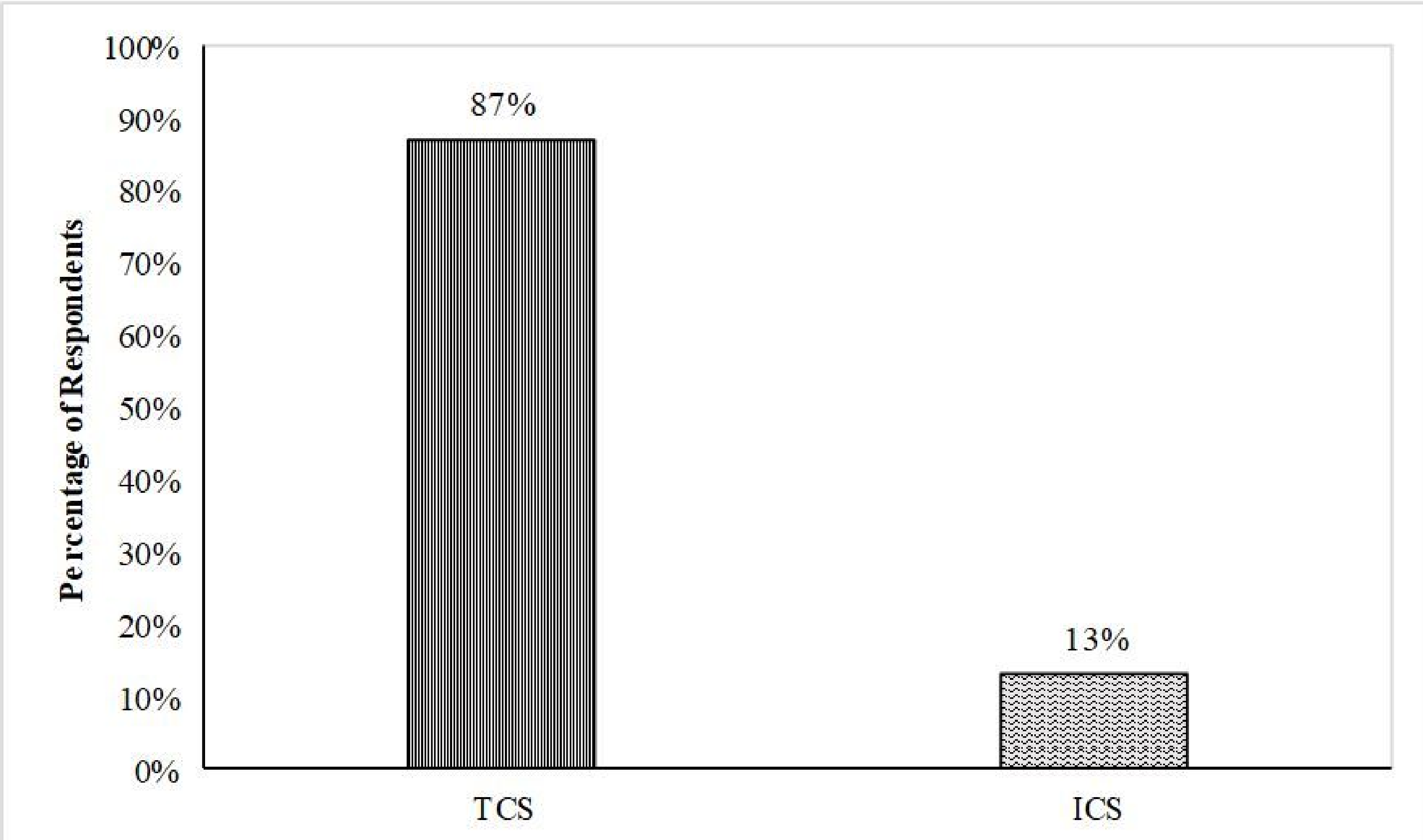



**Figure 4**

Types of cook stoves

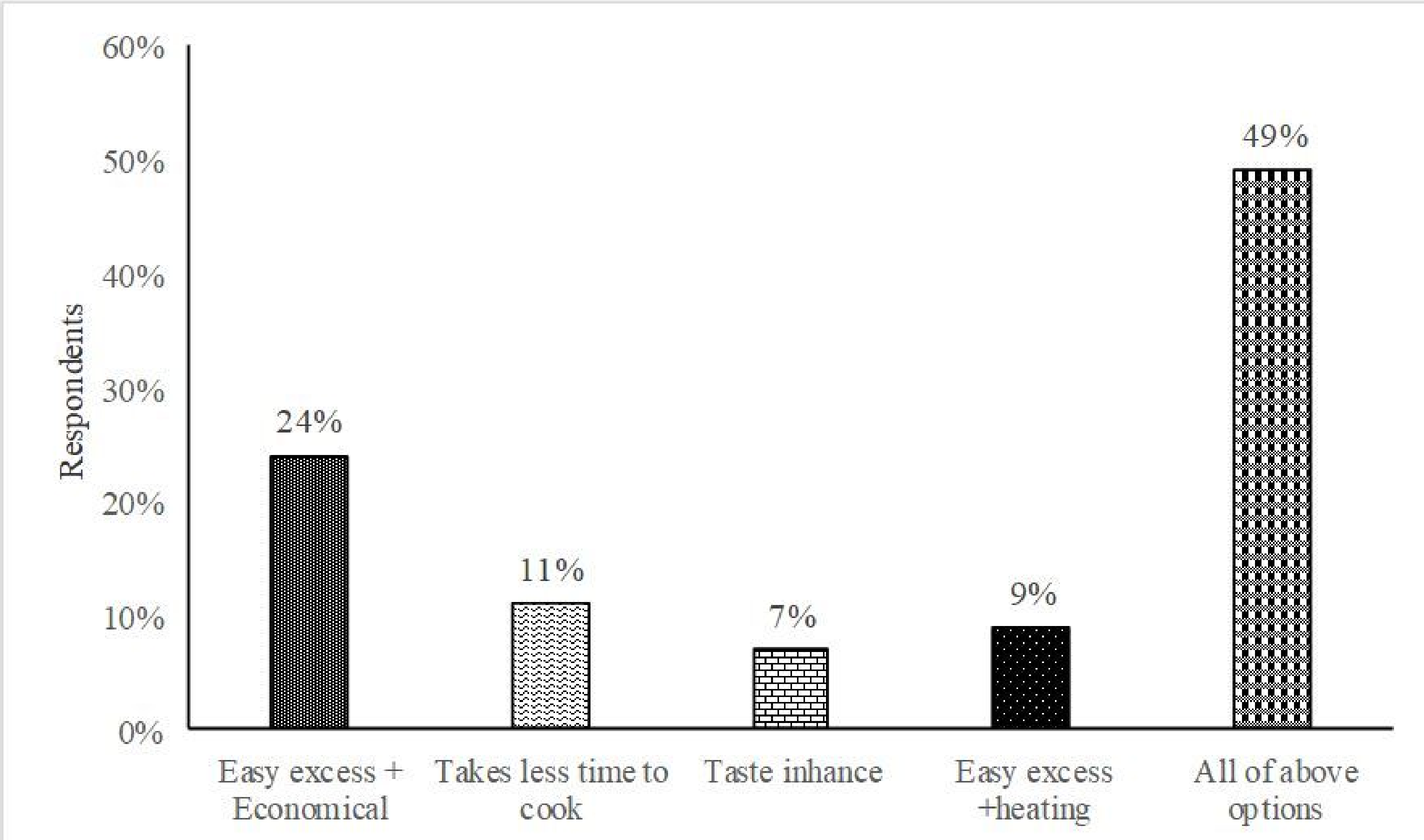



**Figure 5**

Preference of firewood

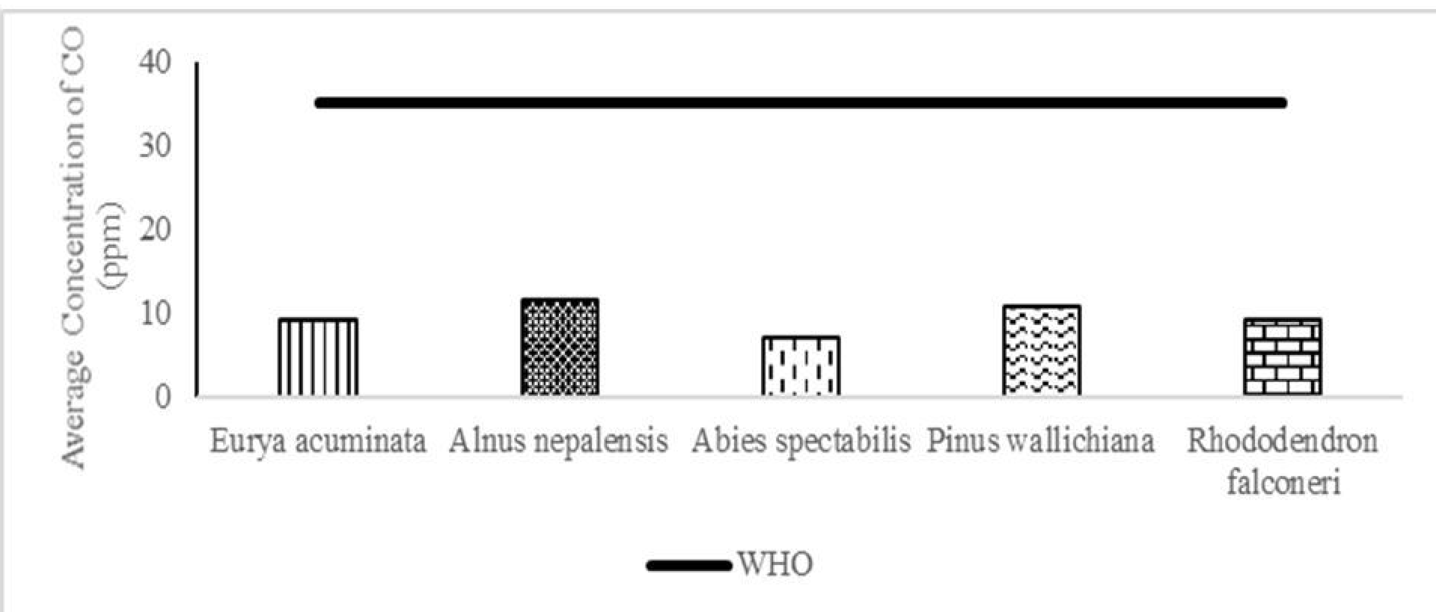



**Figure 6**

Average 1hour concentration of CO in households using ICS

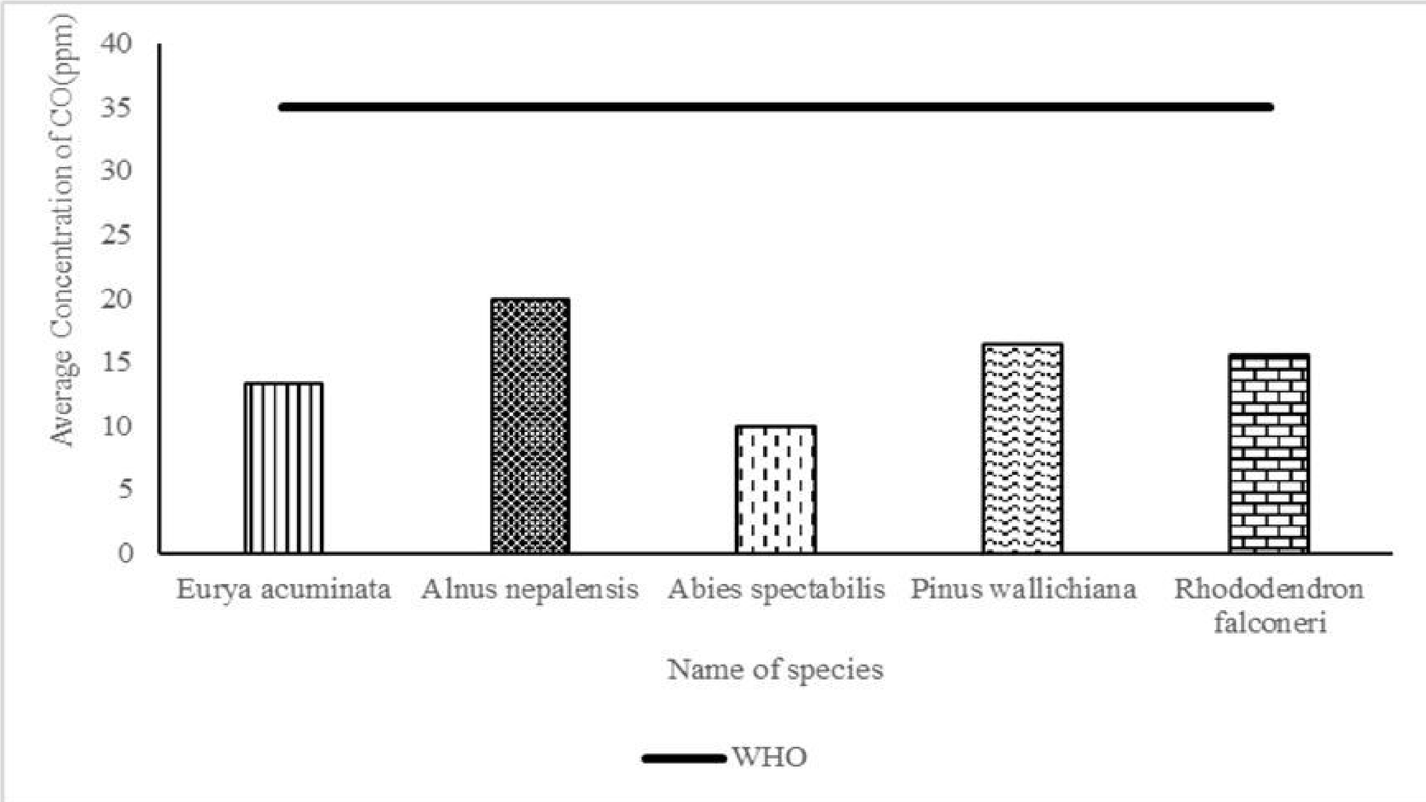



**Figure 7**

Average 1hour concentration of CO in households using TCS

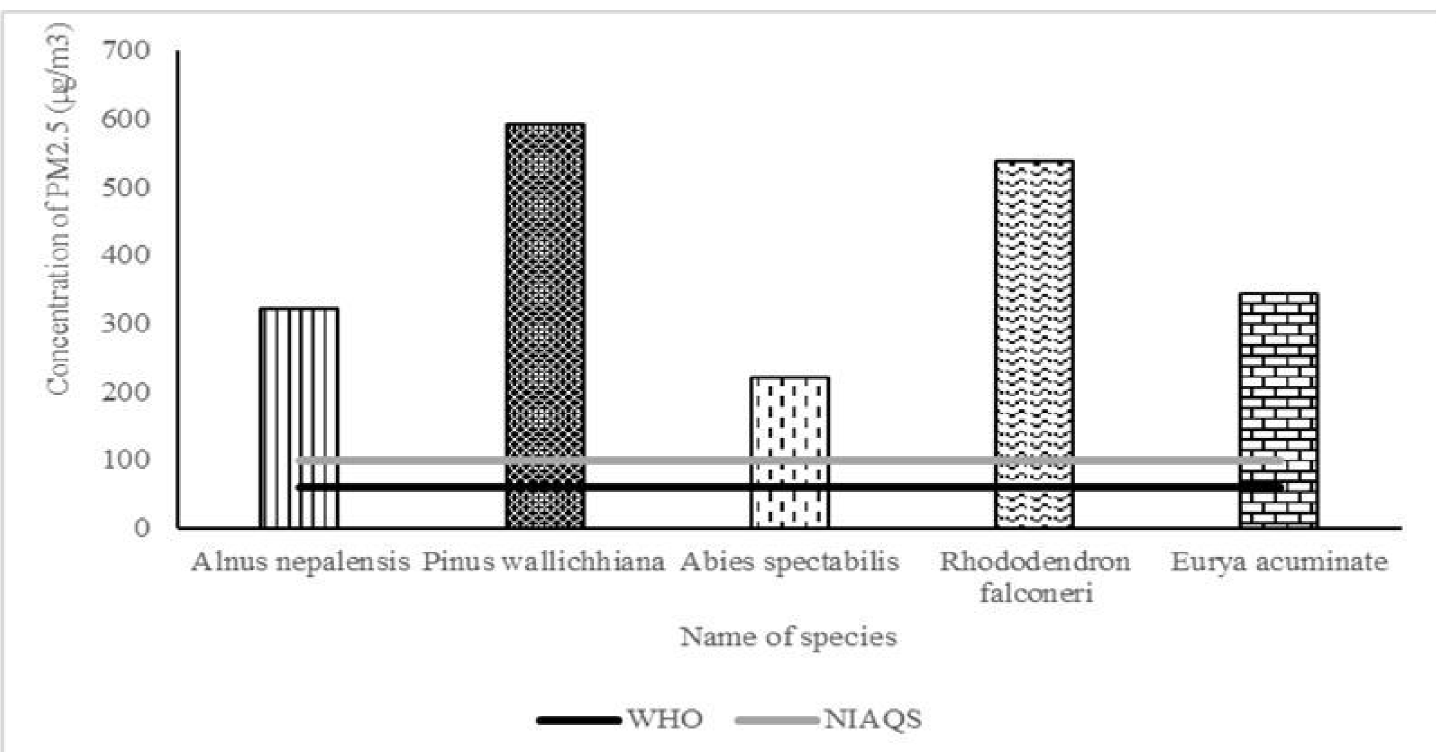
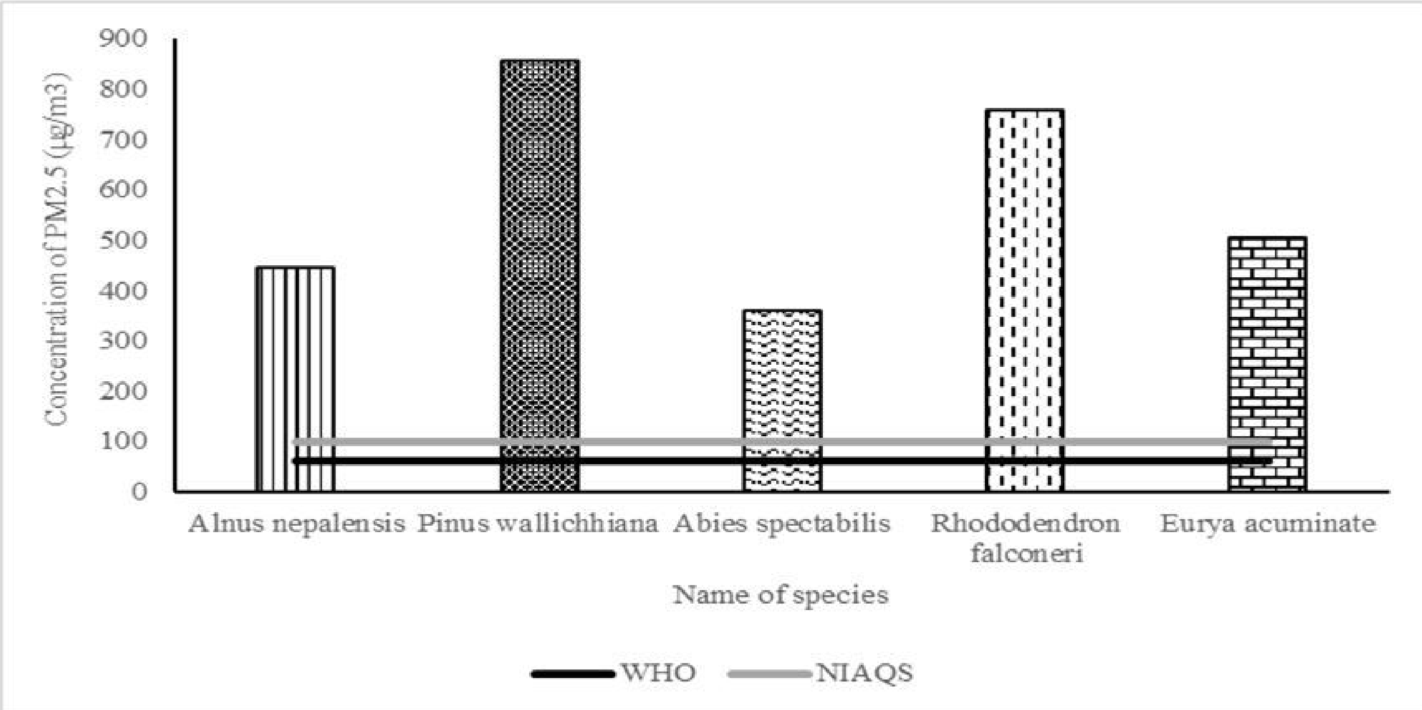


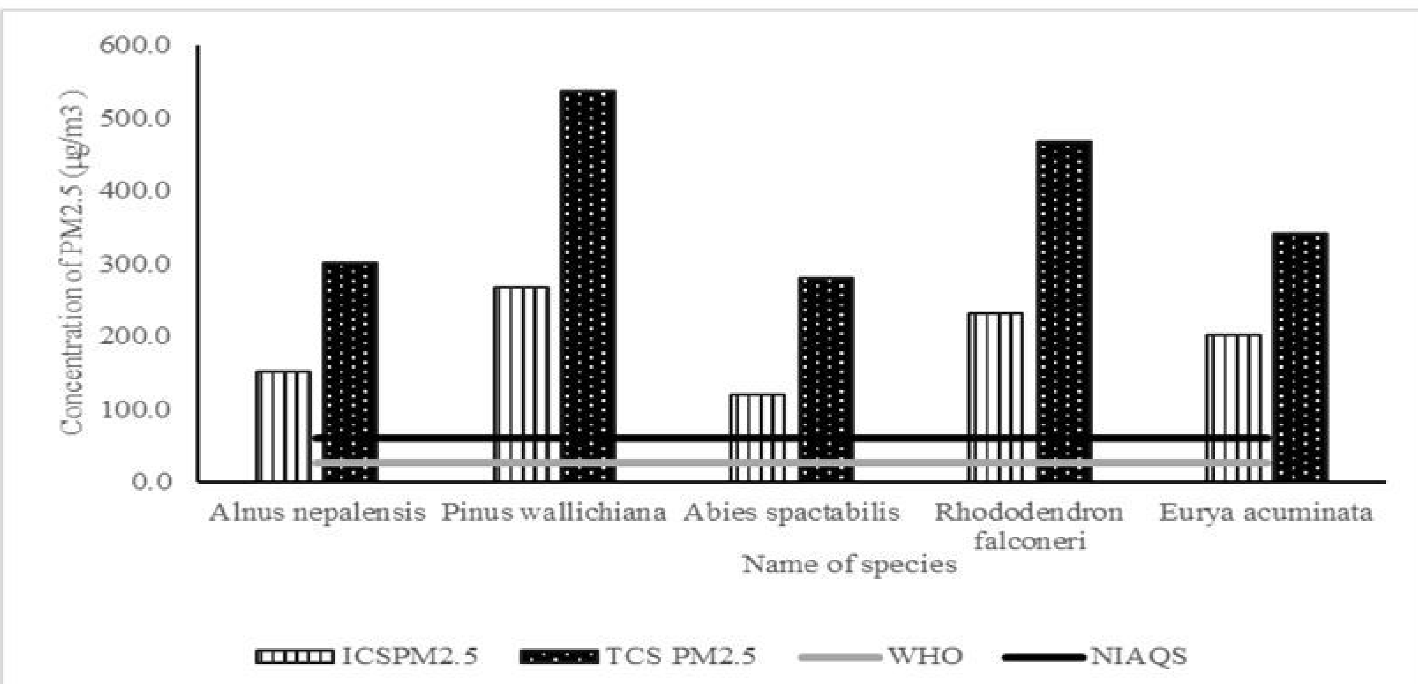

**Figure 8**

Hourly average concentration of PM2.5 in household using ICS




## Figure 9

Hourly average concentration of PM2.5 in household using TCS




## Figure 10

Averages of 8hours CO and 24hours PM2.5 concentration in houses with ICS and